Contents

Preface viii

SECTION I. SYSTEM DESIGN/PROCESS CONTROL

Recent progress in the multi-wafer CBE system
H. Ando, S. Yamaura and T. Fujii 1

Growth of GaInAs(P) using a multiwafer MOMBE
B. Marheineke, M. Popp and H. Heinecke 16

Simple high conductance gas line for high growth rate and low transient
J.L. Benchimol and M. Ancilotti 22

Growth control of GaAs using short-pulse supersonic beam epitaxy
S. Zhang, J. Cui and Y. Aoyagi 28

Real-time optical monitoring of $Ga_xIn_{1-x}P$ and GaP heteroepitaxy on Si under pulsed chemical beam conditions
N. Dietz, U. Rossow, D.E. Aspnes and K.J. Bachmann 34

In-situ monitoring of Si and SiGe growth on Si(001) surfaces during gas-source molecular beam epitaxy using reflectance anisotropy
J. Zhang, A.K. Lees, A.G. Taylor, D. Raisbeck, N. Shukla, J.M. Fernández, B.A. Joyce and M.E. Pemble 40

In-situ pyrometric interferometry monitoring of $In_{0.5}Ga_{0.5}P/In_{0.5}Al_{0.5}P$ material systems during gas-source molecular beam epitaxy growth
D.L. Sato, H.P. Lee, J.M. Kuo and H.C. Kuo 47

SECTION II. KINETICS OF GROWTH AND ETCHING

An in-situ laser-light scattering study of the development of surface topography during GaAs and $In_xGa_{1-x}As$ chemical beam epitaxy
A.R. Boyd, T.B. Joyce and R. Beanland 51

A detailed time of flight study of the cracking pattern trimethylgallium; implications for MOMBE growth
O. Naji, J. Zhang, T. Kaneko, T.S. Jones, J.H. Neave and B.A. Joyce 58

A comparison of RHEED reconstruction phases on (100) InAs, GaAs and InP
B. Junno, S. Jeppesen, M.S. Miller and L. Samuelson 66

Growth mechanisms and morphology of Ar^+ laser assisted CBE of GaAs
A.R. Boyd, T.J. Bullough, T. Farrell and T.B. Joyce 71

P_2-induced P/As exchange on GaAs during gas-source molecular beam epitaxy growth interruptions
C.H. Yan, A.Y. Lew, E.T. Yu and C.W. Tu 77

The effect of III–V ratio at the substrate surface on the quality of inP grown by GSMBE
A.Z. Li, J.X. Chen, M. Qi and Y.C. Ren 84

Behavior of monolayer holes on MBE grown GaAs surfaces during annealing revealed by in situ scanning electron microscopy
N. Inoue, Y. Homma, J. Osaka and T. Araki 88

Compositional micro-area modification of GaAs surfaces by an electron beam under phosphorus flux
H. Okumura and S. Yoshida 92

Temperature dependence of of GaAs chemical etching using $AsCl_3$
J.M. Ortion, Y. Cordier, J.Ch. Garcia and C. Grattepain 97

SECTION III. PRECURSORS

CBE growth of InP using BPE and TBP: a comparative study
C.W. Kim, G.B. Stringfellow and L.P. Sadwick 104

An evaluation of alternative precursors in chemical beam epitaxy: tris-dimethylaminoarsenic, tris-dimethylaminophosphorus, and tertiarybutylphosphine
N.Y. Li, H.K. Dong, W.S. Wong and C.W. Tu 112

Metalorganic molecular beam epitaxy growth and etching of GaSb on flat and high-index surfaces uusing trisdimethylaminoantimony
K. Yamamoto, H. Asahi, T. Hayashi, K. Asami and S. Gonda 117

CBE growth of InGaAs(P) alloys using TDMAAs and TBP
B. Lamare, J.L. Benchimol, P. Ossart and G. Le Roux 122
Atomic force microscopy studies of substrate cleaning using tris(dimethylamino)arsenic and tris(dimethylamino)antimony and investigations of surface decomposition mechanisms
T.J. Whitaker, T. Martin, A.D. Johnson, A.J. Pidduck and J.P. Newly 125

SECTION IV. WIDE BANDGAP MATERIALS

Growth of SiC and III–V nitride thin films via gas-source molecular beam epitaxy and their characterization
R.F. Davis, S. Tanaka, L.B. Rowland, R.S. Kern, Z. Sitar, S.K. Ailey and C. Wang 132
Growth of Group III nitrides by chemical beam epitaxy
J.D. Mackenzie, C.R. Abernathy, J.D. Stewart and G.T. Muhr 143
Observation of MBE-grown cubic-GaN/GaAs and cubic-GaN/3C–SiC interfaces by high resolution transmission electron microscope
H. Okumura, K. Ohta, T. Nagatomo and S. Yoshida 149
III–N light emitting diodes fabricated using RF nitrogen gas source MBE
J.M. Van Hove, G. Carpenter, E. Nelson, A. Wowchak and P.P. Chow 154
Growth of GaN by gas-source molecular beam epitaxy by ammonia and by plasma generated nitrogen radicals
W.S. Wong, N.Y. Li, H.K. Dong, F. Deng, S.S. Lau, C.W. Tu, J. Hays, S. Bidnyk and J.J. Song 159
The investigation of GaN growth on silicon and sapphire using in-situ time-of-flight low energy ion scattering and RHEED
W.T. Taferner, A. Bensaoula, E. Kim and A. Bousetta 167
Extremely large N content (up to 10%) in GaNAs grown by gas-source molecular beam epitaxy
M. Kondow, K. Uomi, T. Kitatani, S. Watahiki and Y. Yazawa 175
Growth study of chemical beam epitaxy of GaN_xP_{1-x} using NH_3 and tertiarybutylphosphine
N.Y. Li, W.S. Wong, D.H. Tomich, H.K. Dong, J.S. Solomon, J.T. Grant and C.W. Tu 180
The nitridation of GaAs and GaN deposition on GaAs examined by in situ time-of-flight low energy ion scattering and RHEED
A. Bensaoula, W.T. Taferner, E. Kim and A. Bousetta 185
An investigation of ZnSe growth by chemical beam epitaxy using modulated beam scattering and related techniques
J.S. Foord, C.L. Levoguer and G.J. Davies 190
MO(GS)MBE and photo-MO(GS)MBE of II–VI semiconductors
Sz. Fujita, Y. Kawakami and Sg. Fujita 196
Kinetics of chemical beam epitaxy for high quality ZnS film growth
W. Tong, B.K. Wagner, T.K. Tran, W. Ogle, W. Park and C.J. Summers 202
Growth and mechanistic studies of diamond formation by chemical beam epitaxy using methyl and acetylene precursors
J.S. Foord, K.P. Loh, N.K. Singh, R.B. Jackman and G.J. Davies 208

SECTION V. GROWTH ON SI SUBSTRATES

Growth and doping of Si and SiGe films by hydride gas-source molecular beam epitaxy
B.A. Joyce, J.M. Fernández, M.H. Xie, A. Matsumura, J. Zhang and A.G. Taylor 214
Gas source MBE growth of Si/SiGe device materials
K. Werner, A. Storm, S. Butzke, J.W. Maes, M. van Rooy, P. Alkemade, E. Algra, M. Somers, B. de Lange, E. van der Drift, T. Zijlstra and S. Radelaar 223
Investigation of facet formation and competition in MBE growth
S. Li, Q. Xiang, D. Wang and K.L. Wang 235
Silicon/silicon–germanium multiple quantum wells grown by gas-source molecular beam epitaxy: hydrogen coverage and interfacial abruptness
J.M. Fernández, L. Hart, X.M. Zhang, M.H. Xie, J. Zhang and B.A. Joyce 241
Initial growth stages of $Al_xGa_{1-x}P$ on epitaxial silicon
C.J. Santana, C.R. Abernathy, S.J. Pearton and K.S. Jones 248
Growth studies of GaP on Si by gas-source molecular beam epitaxy
W.G. Bi, X.B. Mei and C.W. Tu 256

SECTION VI. STRAINED LAYER AND HETEROEPITAXY

Substitution of InP layers to InAs for strain compensation in $Ga_xIn_{1-x}As/InP$ superlattices
R.T.H. Rongen, M.R. Leys, H. Vonk, J.H. Wolter and Y.S. Oei 263

Strain balanced GaP/GaAs/InP/GaAs superlattices: structural and electronic properties
A.H. Bensaoula and A. Freundlich 271
Synthesis of highly strained $In_xGa_{1-x}P/In_xGa_{1-x}As/In_xGa_{1-x}P$ quantum well structures with strain compensation
C.H. Yan and C.W. Tu 276
GSMBE growth and PL investigation of lattice-matched InGaAs/InP quantum wells
Wang Xiaoliang, Sun Dianzhao, Kong Meiying, Hou Xun and Zeng Yiping 281
Epitaxial dysprosium phosphide grown by gas-source and solid-source MBE on gallium arsenide substrates
L.P. Sadwick, P.P. Lee, M. Patel, M. Nikols, R.J. Hwu, J.E. Shield, D.C. Streit, D. Brehmer, K. McCormick, S.J. Allen and R.W. Gedridge 285

SECTION VII. SELECTIVE OR NON-PLANAR EPITAXY

In situ selective area growth of GaAs, AlAs, and AlGaAs using MOMBE
S. Yoshida and M. Sasaki 291
Increasing the range of growth temperatures available for GaAs selective area growth using triisopropylgallium and arsine
T.J. Whitaker, T. Martin and R.W. Freer 296
Beam geometrical effects on planar selective area epitaxy of InP/GaInAs heterostructures
M. Wachter and H. Heinecke 302
Grown mirrors of InP formed by dry etching and selective CBE regrowth for short cavity lasers
M. Gotoda, H. Sugimoto, T. Isu and M. Nunoshita 308
Selective area chemical beam epitaxy for butt-coupling integration
P. Legay, F. Alexandre, J.L. Benchimol, M. Allovon, F. Laune and S. Fouchet 314
Growth temperature dependence of the interfacet migration in chemical beam epitaxy of InP on non-planar substrates
C. Amano, A. Rudra, P. Grunberg, J.F. Carlin and M. Ilegems 321
Chemical beam epitaxy on patterned substrates of InGaAs/InP heterostructures for optoelectronics and nanostructures applications
C. Rigo, R. Vincenzoni, A. Stano and R. De Franceschi 327
Selective InAs growth by chemical beam epitaxy
K. Shiralagi, M. Walther, R. Tsui and H. Goronkin 334
MOMBE selective infill growth of InP:Si and InGaAs:Si and large area MOMBE regrowth
S. Schelhase, J. Böttcher, R. Gibis, H. Künzel and A. Paraskevopoulos 339
Directional dependence of InAs island formation on patterned GaAs
M.S. Miller, S. Jeppesen, B. Kowalski, I. Maximov and L. Samuelson 345
Fabrication of InGaAs/GaAs quantum wires on a non-(111) V-grooved GaAs substrate by chemical beam epitaxy
Sung-Bock Kim, Seong-Ju Park, Jeong-Rae Ro and El-Hang Lee 356

SECTION VIII. DOPING

Materials and electrical characteristics of carbon-doped $Ga_{0.47}In_{0.53}As$ using carbontetrabromide by MOMBE for HBT device applications
R.A. Hamm, S. Chandrasekhar, L. Lunardi, M. Geva, R. Malik, D. Humphrey and R. Ryan 362
Growth of carbon-doped GaAs, AlGaAs and InGaAs by chemical beam epitaxy and the application of in-situ monitoring
T.B. Joyce, S.P. Westwater, P.J. Goodhew and R.E. Pritchard 371
CBE growth of carbon-doped p-type InGaAs using trimethylindium and unprecracked monoethylarsine as carbon auto-doping precursor
Jeong-Rae Ro, Seong-Ju Park, Sung-Bock Kim and El-Hang Lee 377
Characterization of carbon delta-doping GaAs superlattices grown by chemical beam epitaxy using CBr_4
B.R. Davidson, L. Hart, R.C. Newman, T.B. Joyce and T.J. Bullough 383
The use of CBr_4 and $SiBr_4$ doping in MOMBE and application to InP-based heterojunction bipolar transistor structures
E.A. Beam III and H.F. Chau 389
The rotation of the alignment by 90° of $(H–(C_{As})_2)$ complexes resulting from metalorganic molecular beam epitaxy or metalorganic vapour phase epitaxy growth on GaAs(001) using trimethylgallium
B.R. Davidson, R.C. Newman, T. Kanedo, O. Naji and K.H. Bachem 396
Zn doping of InP/GaInAsP device structures in metalorganic molecular beam epitaxy using diethylzinc
E. Veuhoff, H. Baumeister, R. Treichler, M. Popp and H. Heinecke 402
Surface morphologies of Be-doped homoepitaxial InP films
M.A. Cotta, M.M.G. de Carvalho, M.A.A. Pudenzi, K.M.I. Landers, C.F. de Souza, R.B. Martins, R. Landers and O. Teschke 409

Sulphur doping of InGaAs using diethylsulphide
G.M. Petkos, P.J. Goodhew and T.B. Joyce 415
Tellurium doping of InP using triisopropylindium–diisopropyltellurium (TIPIn–DIPTe)
M.J. Antonell, C.R. Abernathy and R.W. Gedridge 420
Influence of H_2 on electrical and optical properties of carbon-doped InP grown by MOMBE using tertiarybutylphosphine (TBP)
J.-H. Oh, F. Fukuchi, H.-C. Kang and M. Konagai 425
InP:Fe semi-insulating layers by chemical beam epitaxy
C. Rigo, M. Madella, C. Papuzza, C. Cacciatore, A. Stano, A. Gasparotto, G. Salviati and L. Nasi 430

SECTION IX. III–V DEVICES

MOMBE growth of InAsP laser materials
H. Sugiura 434
Strained GaInAs/InP MQW layers grown by CBE for optical components
C.G.M. Vreeburg, Y.S. Oei, B.H. Verbeek, J.J.G.M. van der Tol, R.T.H. Rongen, H. Vonk, M.R. Leys, B.H.P. Dorren and J.H. Wolter 442
MOMBE growth of high quality GaInAsP ($\lambda_g = 1.05\ \mu m$) for waveguide applications
H. Künzel, P. Albrecht, R. Gibis, M. Hamacher and S. Schelhase 449
Co-integration of high speed InP-based HBTs and RTDs using chemical beam epitaxy
W.L. Chen, G.O. Munns, X. Wang and G.I. Haddad 454
Parametric study on lattice-matched and pseudomorphic InGaAs/InAlAs/InP modulation-doped heterostructures grown by GSMBE
J.X. Chen, A.Z. Li, Y.C. Ren, M. Qi and Y.G. Chang 460
First epitaxial InP tunnel junctions grown by chemical beam epitaxy
M.F. Vilela, N. Medelci, A. Bensaoula, A. Freundlich and P. Renaud 465
Pseudomorphic InGaAs/In(Ga)P bidimensional electron gas grown by chemical beam epitaxy
J.F. Carlin, A. Rudra and M. Ilegems 470
Heterojunction bipolar transistors with low temperature Be-doped base grown by CBE
G.O. Munns, W.L. Chen and G.I. Haddad 476
Device quality AlGaAs grown by chemical beam epitaxy
W.T. Moore, P. Mandeville, R.W. Streater and C.J. Miner 485
Growth of resonant interband tunneling diodes using trimethylamine alane
R. Tsui, K. Shiralagi and J. Shen 491

Author index 496

Subject index 502